Natural SUSY On Trial:
Status of Higgsino Searches at ATLAS

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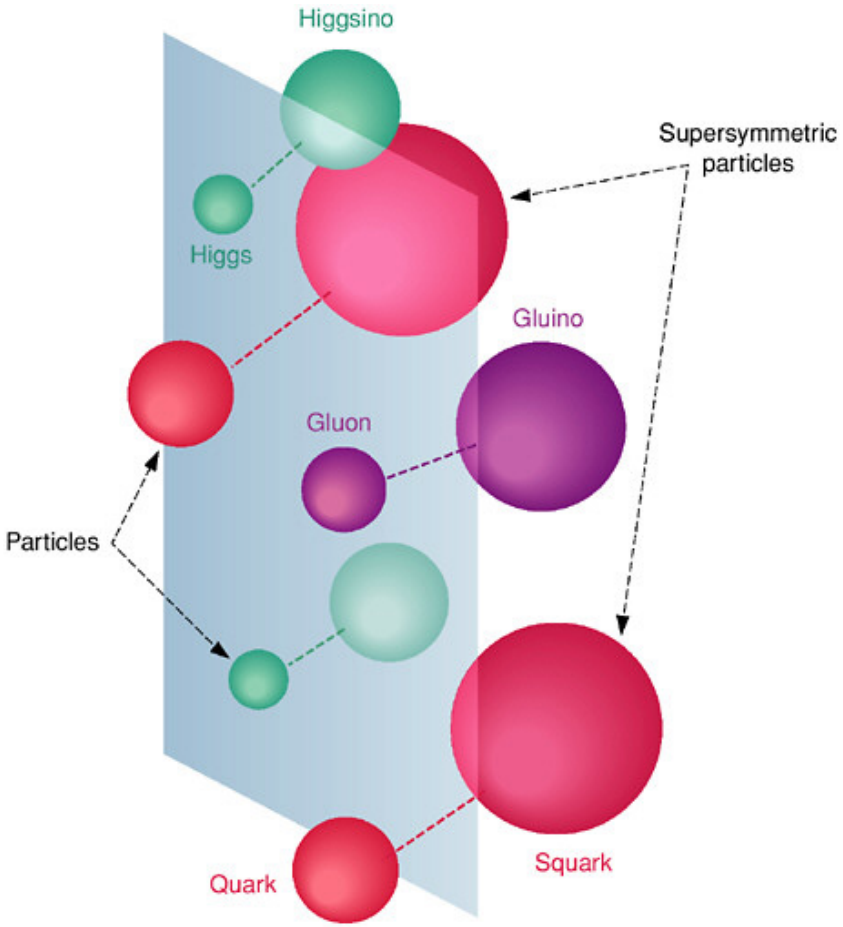
US LHC User's Association
Annual Meeting

SUSY (The Defendant)

- Provides unification of forces, dark matter candidate, and solution to hierarchy problem
- Higgs mass quadratic corrections cancelled by new supersymmetric partners; higgsinos, stops and gluinos especially influential

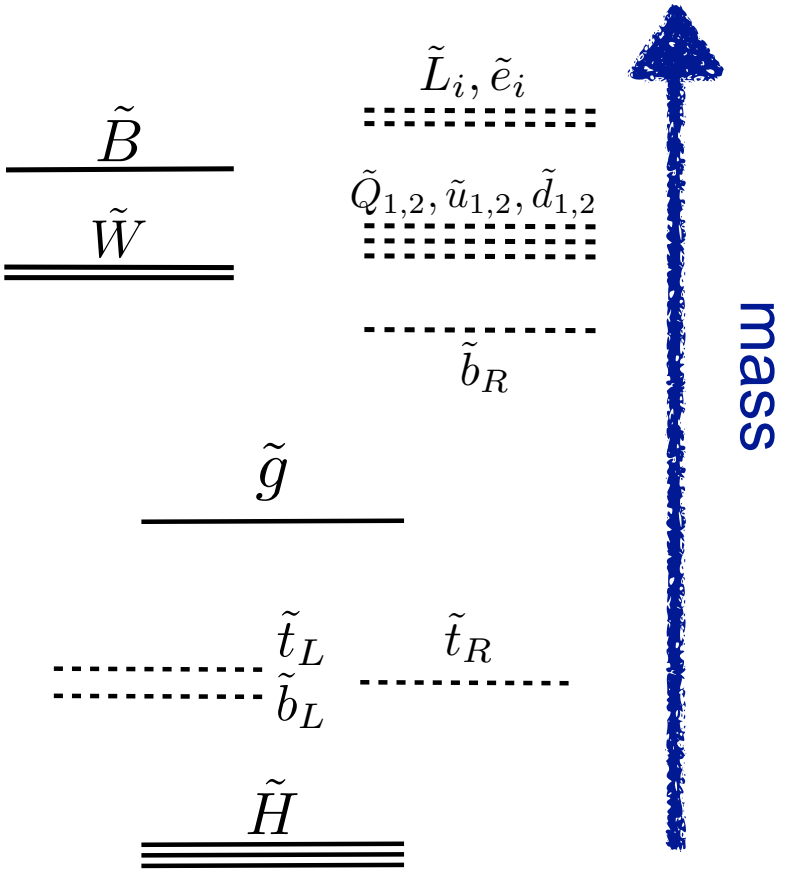
➡ What do we search for first?



SUSY Mass Spectrum

(if we got to pick)

- **Naturalness** = reduce fine tuning $\Longrightarrow$ 10%



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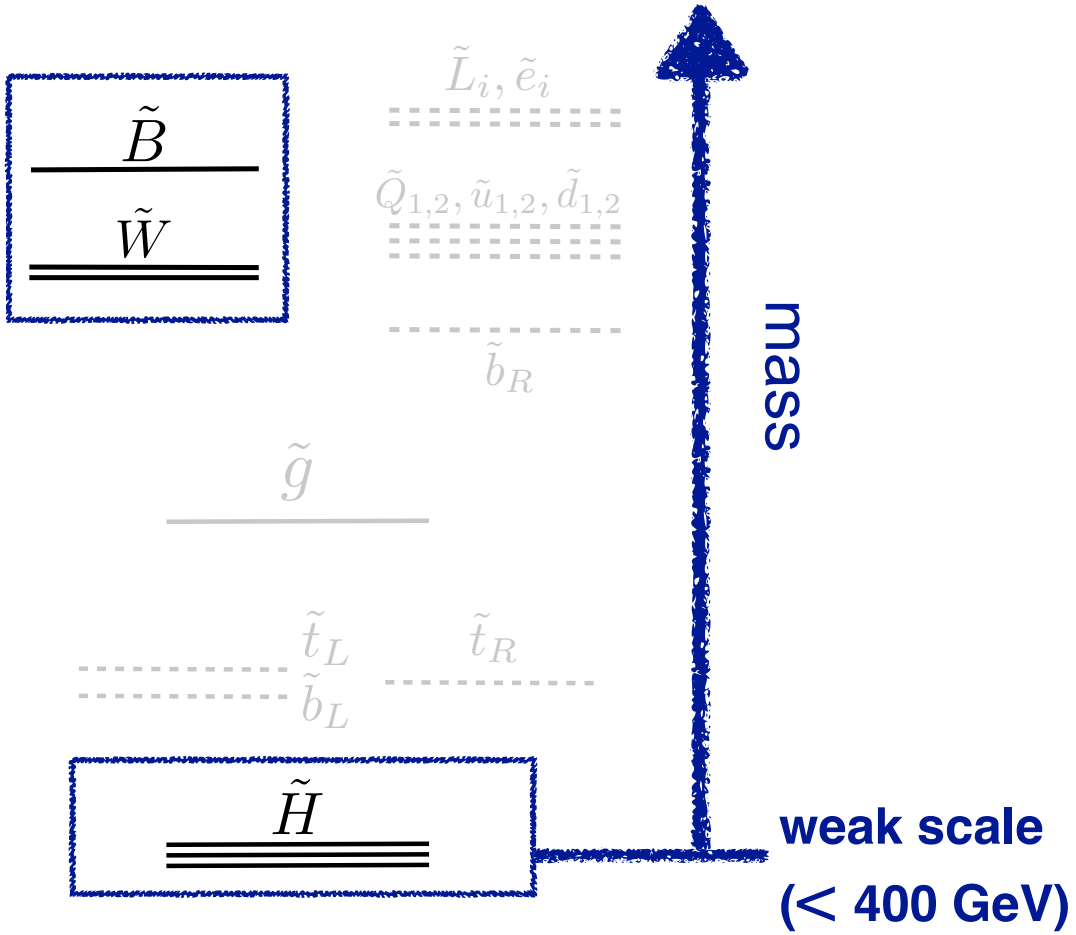

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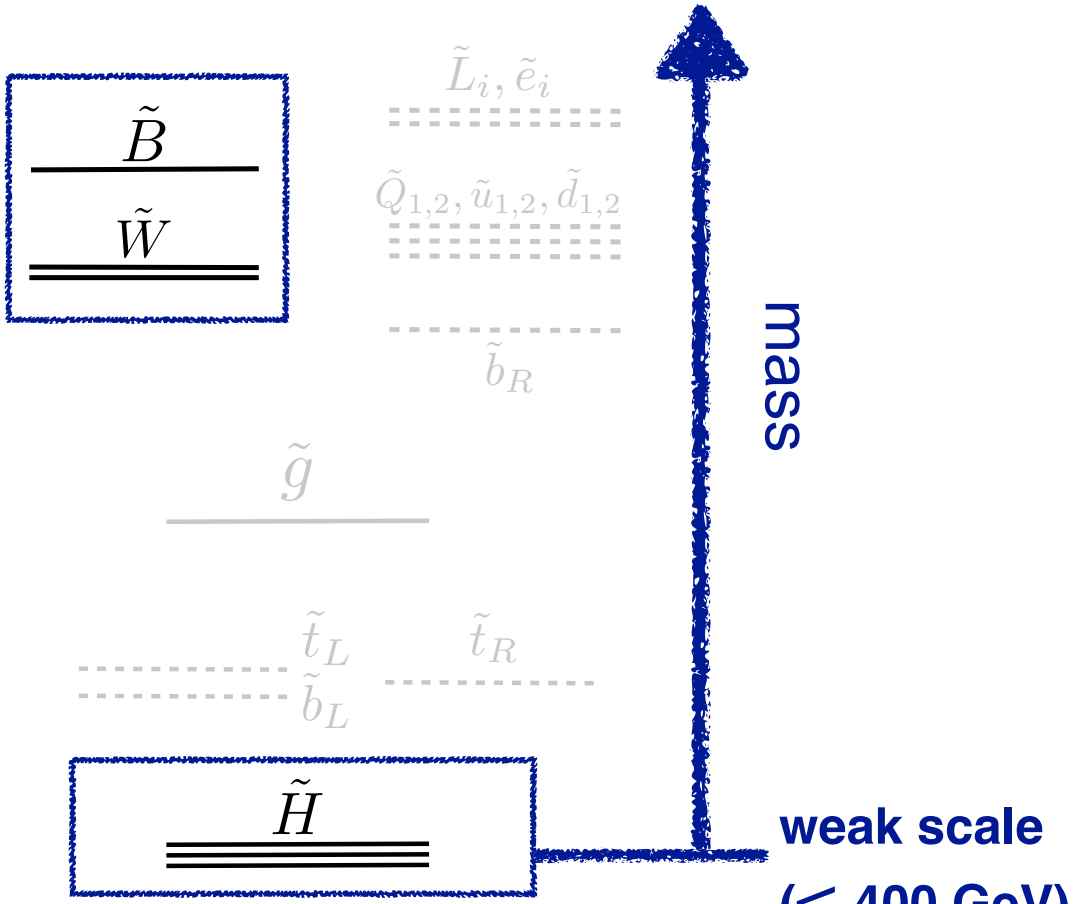

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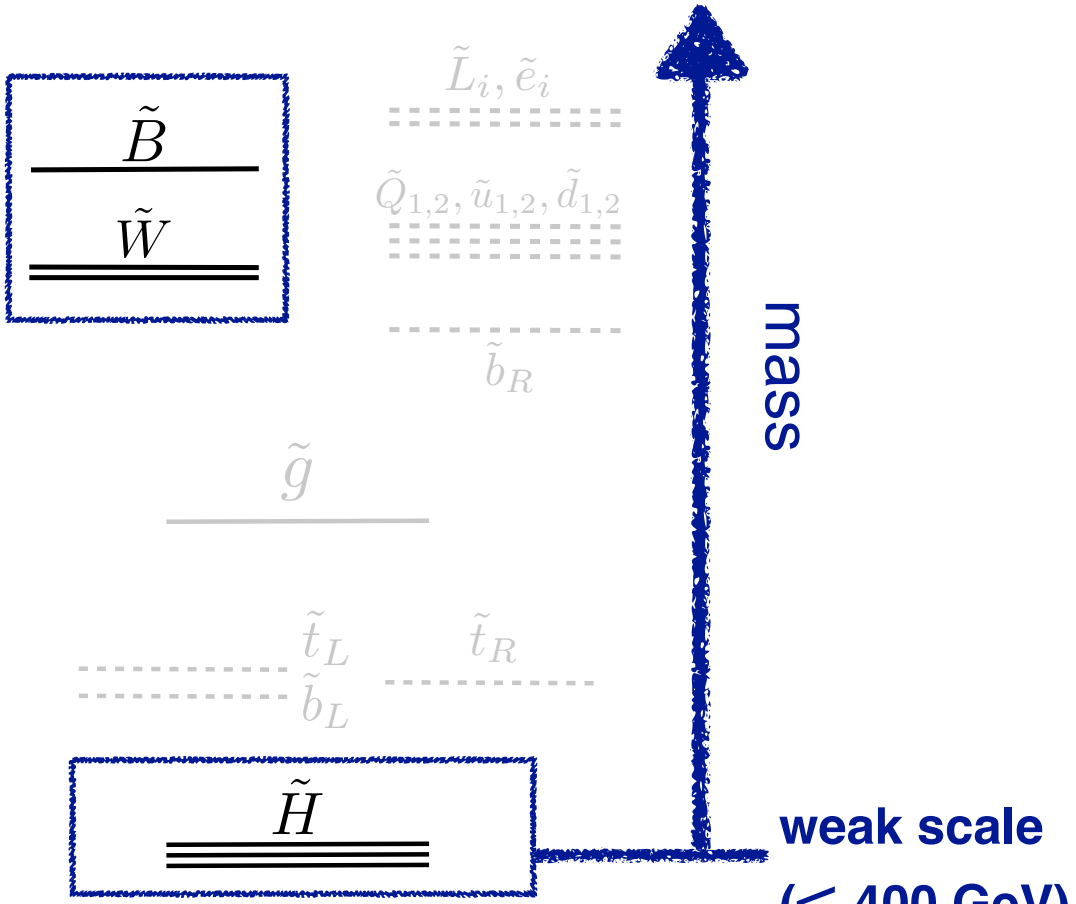

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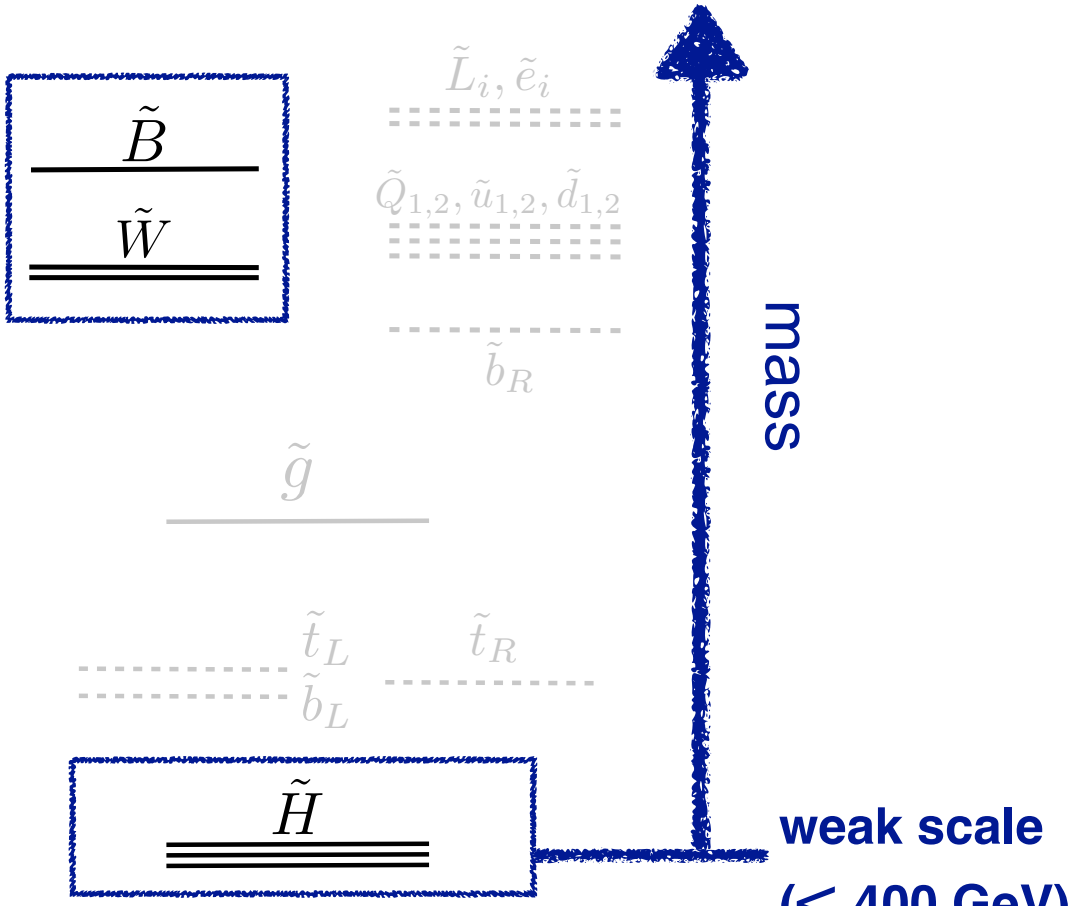
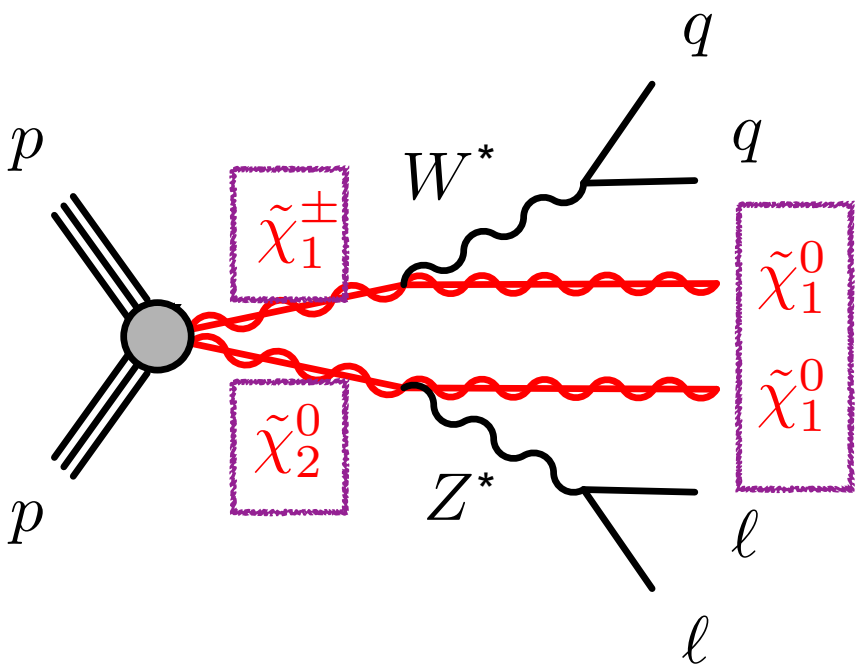
- Lightest three ewkinos are *compressed* (Δm ~ few GeV)



Higgsino Searches at ATLAS

- Final state: 2 opposite sign same flavor soft leptons



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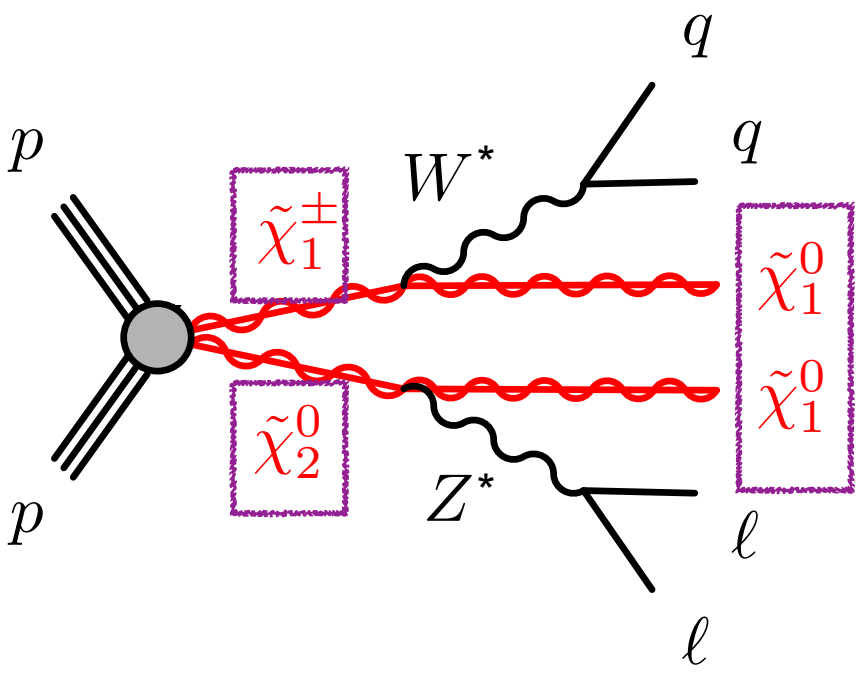

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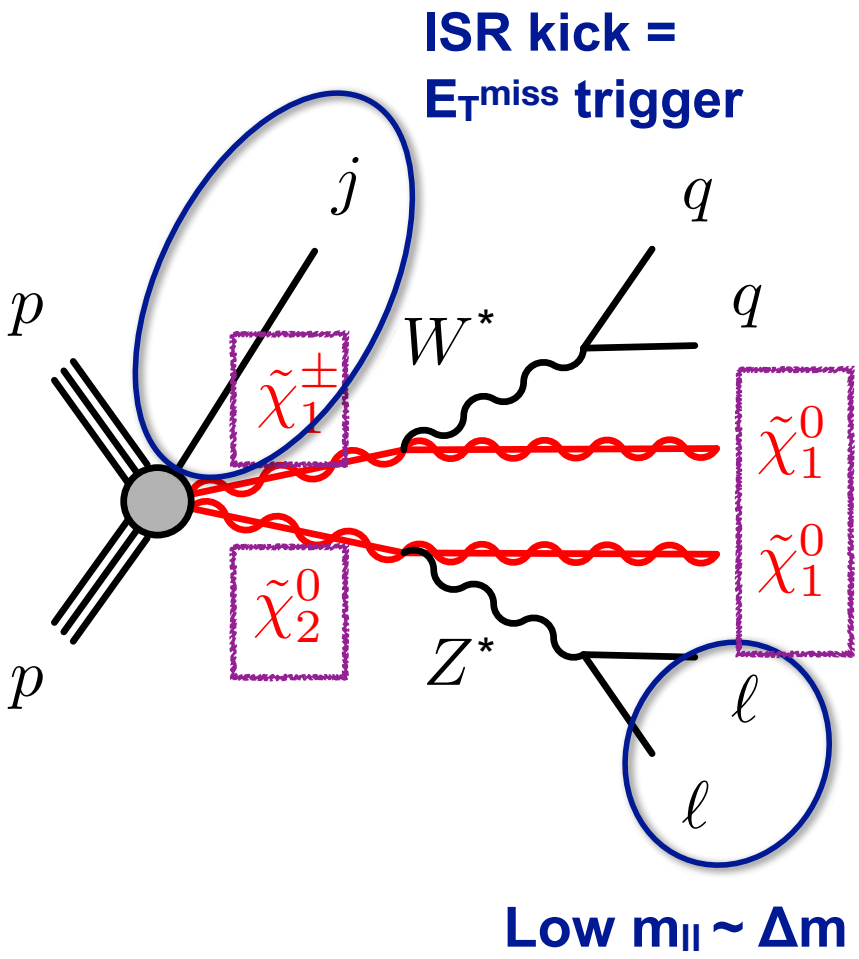
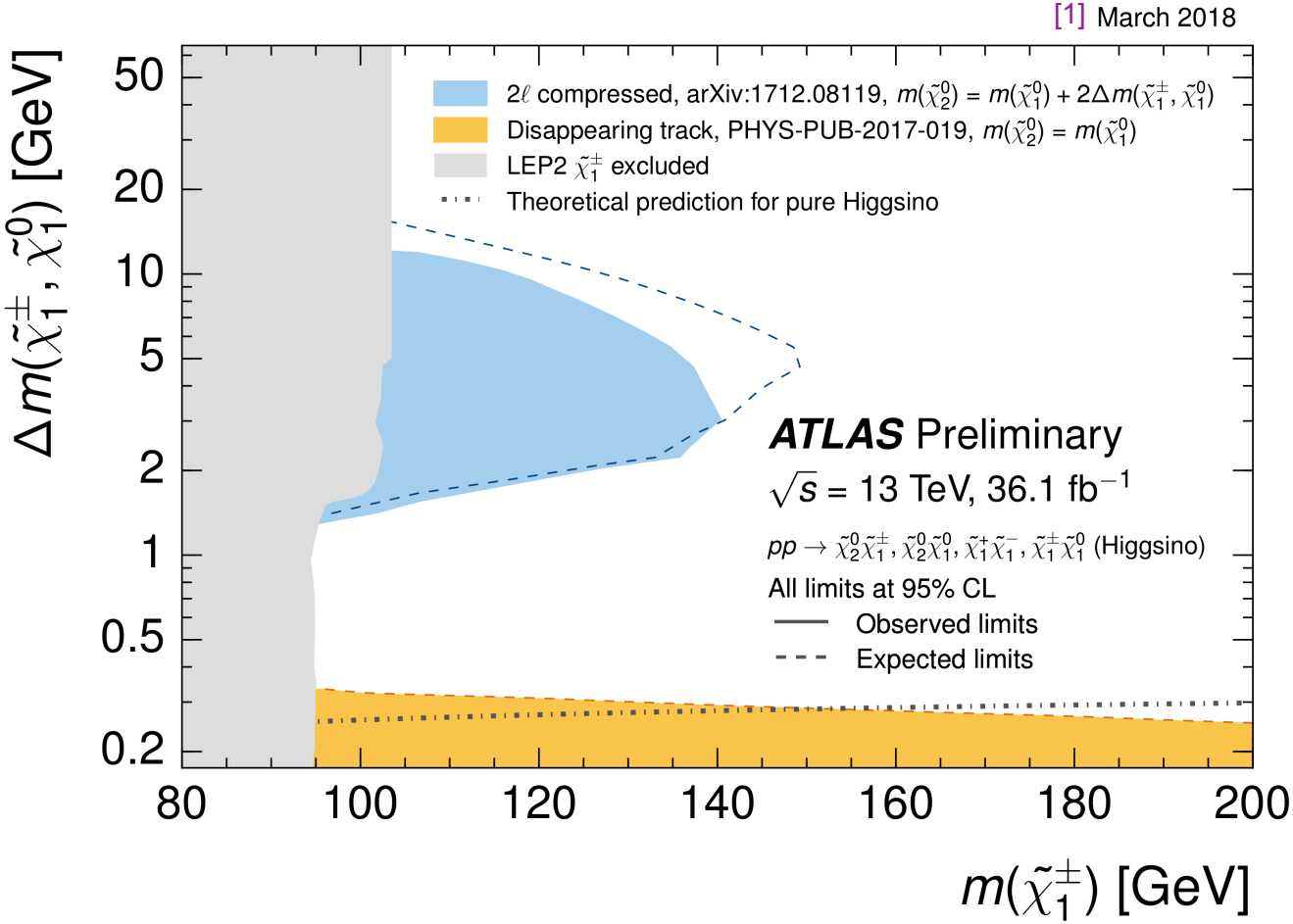


Current Exclusion

[1] March 2018



[1] ATLASSummaryPlots

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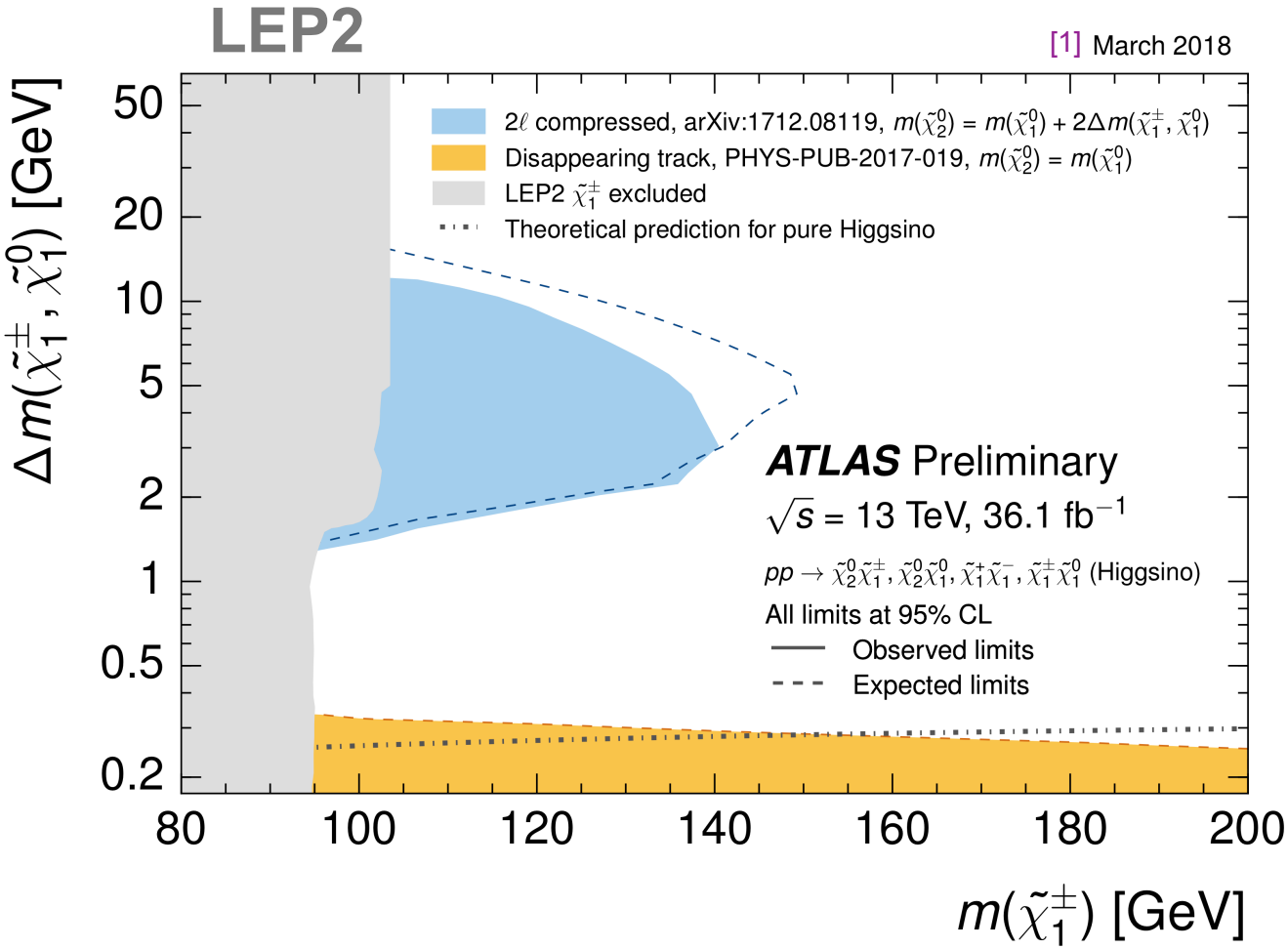

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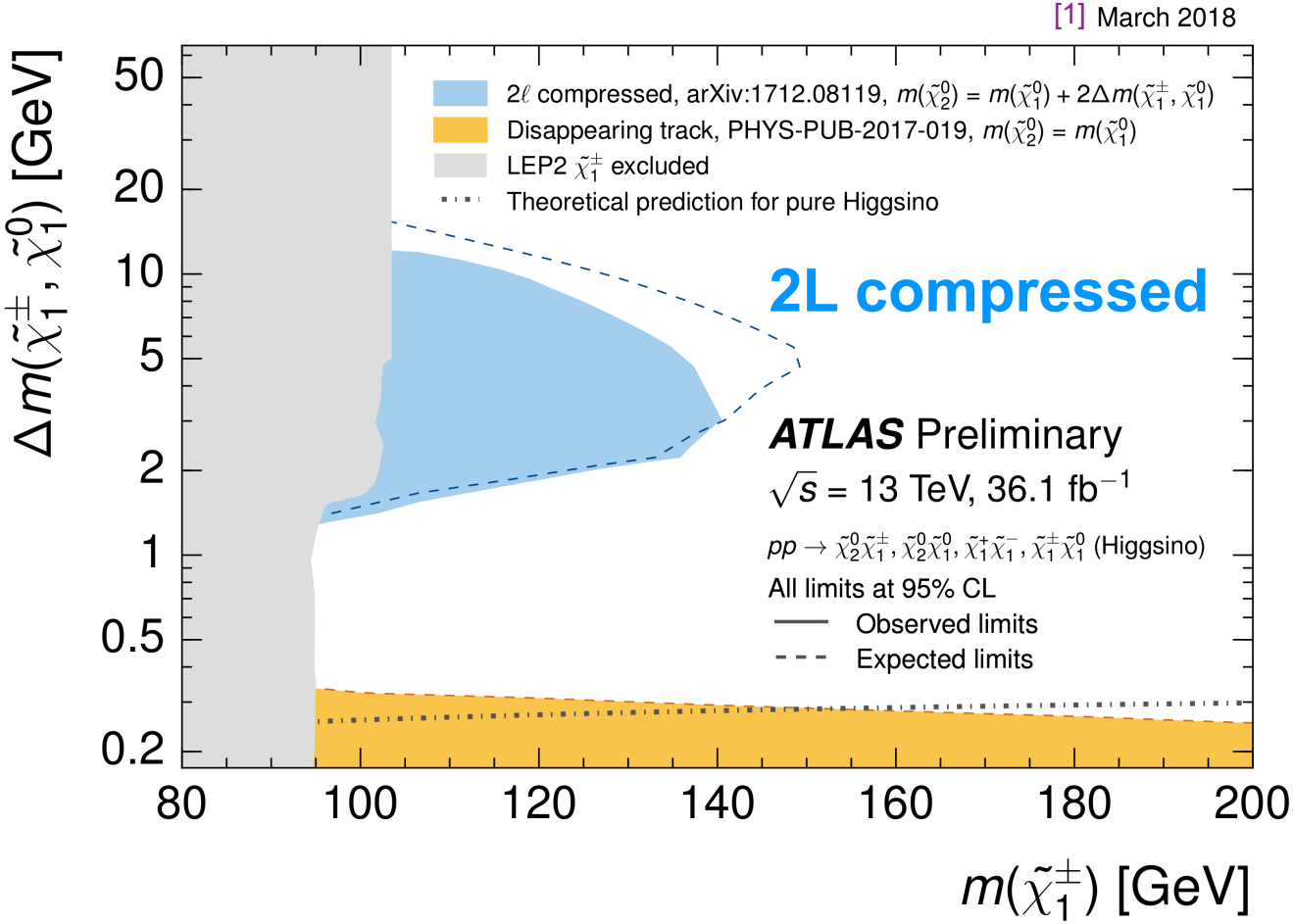

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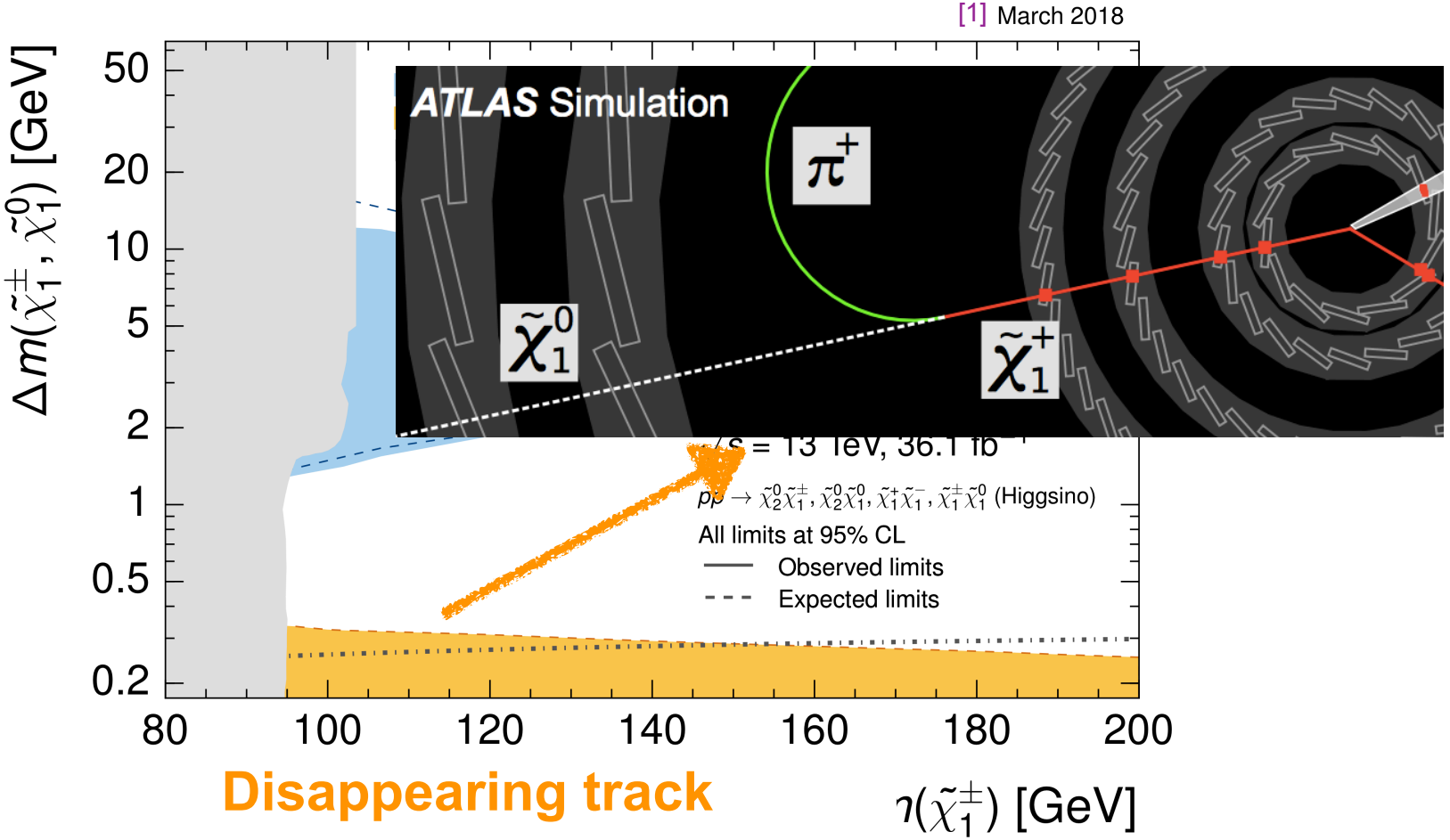

Disappearing track

Pure higgsino/wino state:
$\Delta m \sim 100$ MeV $\Rightarrow$ long lifetime $\sim 10^{-11}$s [2]

[2] ATL-PHYS-PUB-2017-19

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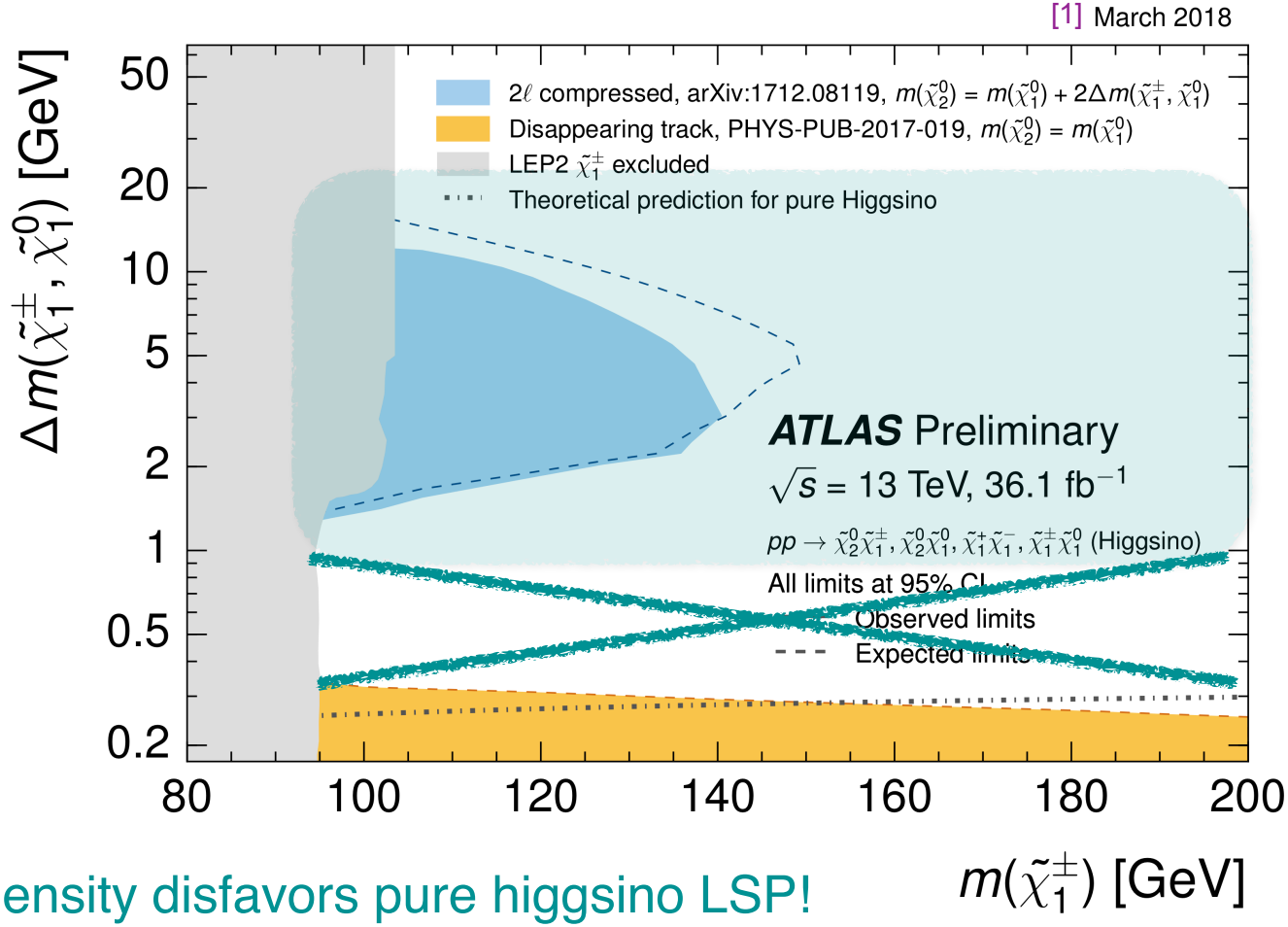


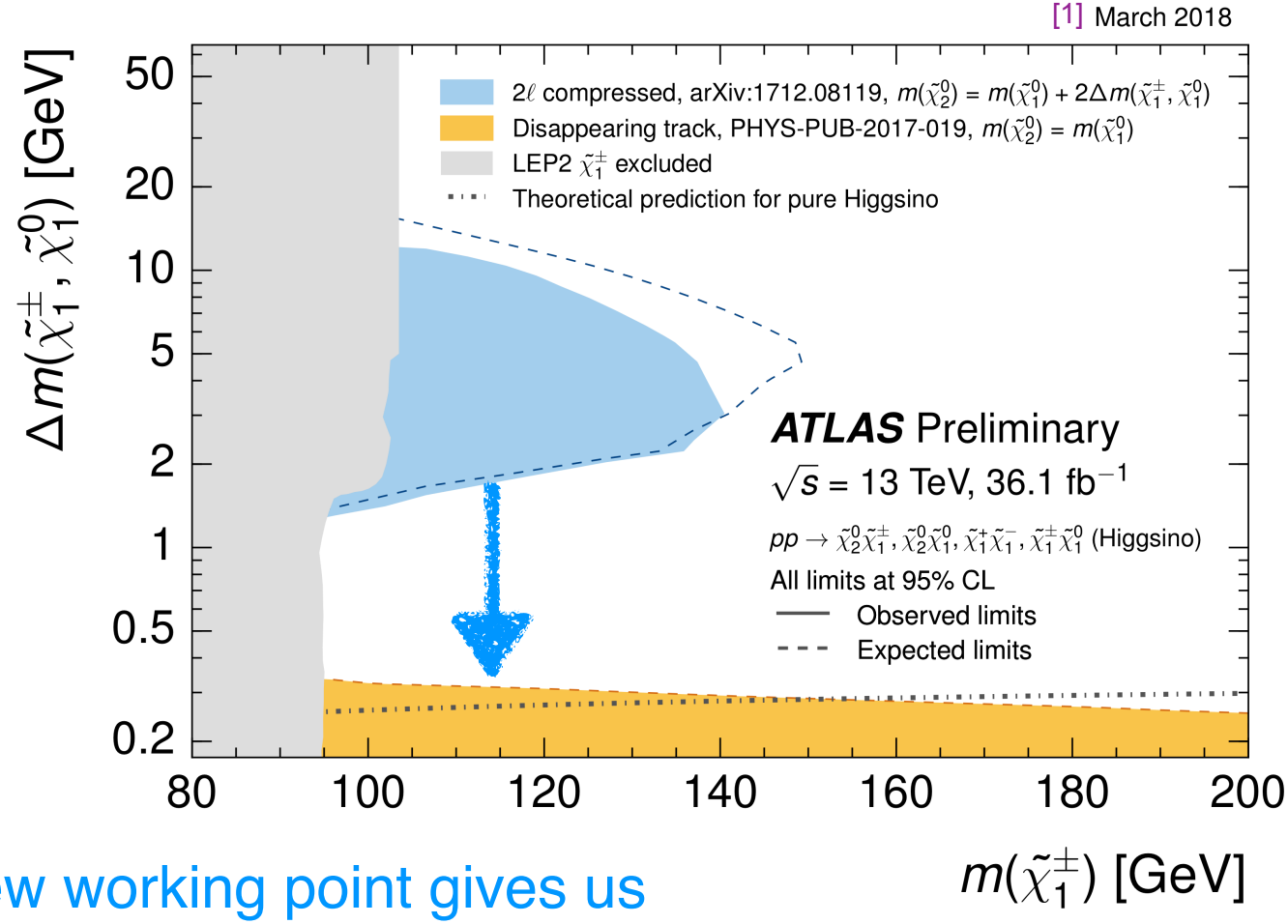
Relic density disfavors pure higgsino LSP!
(Well-Tempered Neutralino) [3]

[3] arXiv:0601041

[1] ATLASSummaryPlots

Areas of Improvement

[1] March 2018



New working point gives us muons down to 3 GeV (2019)

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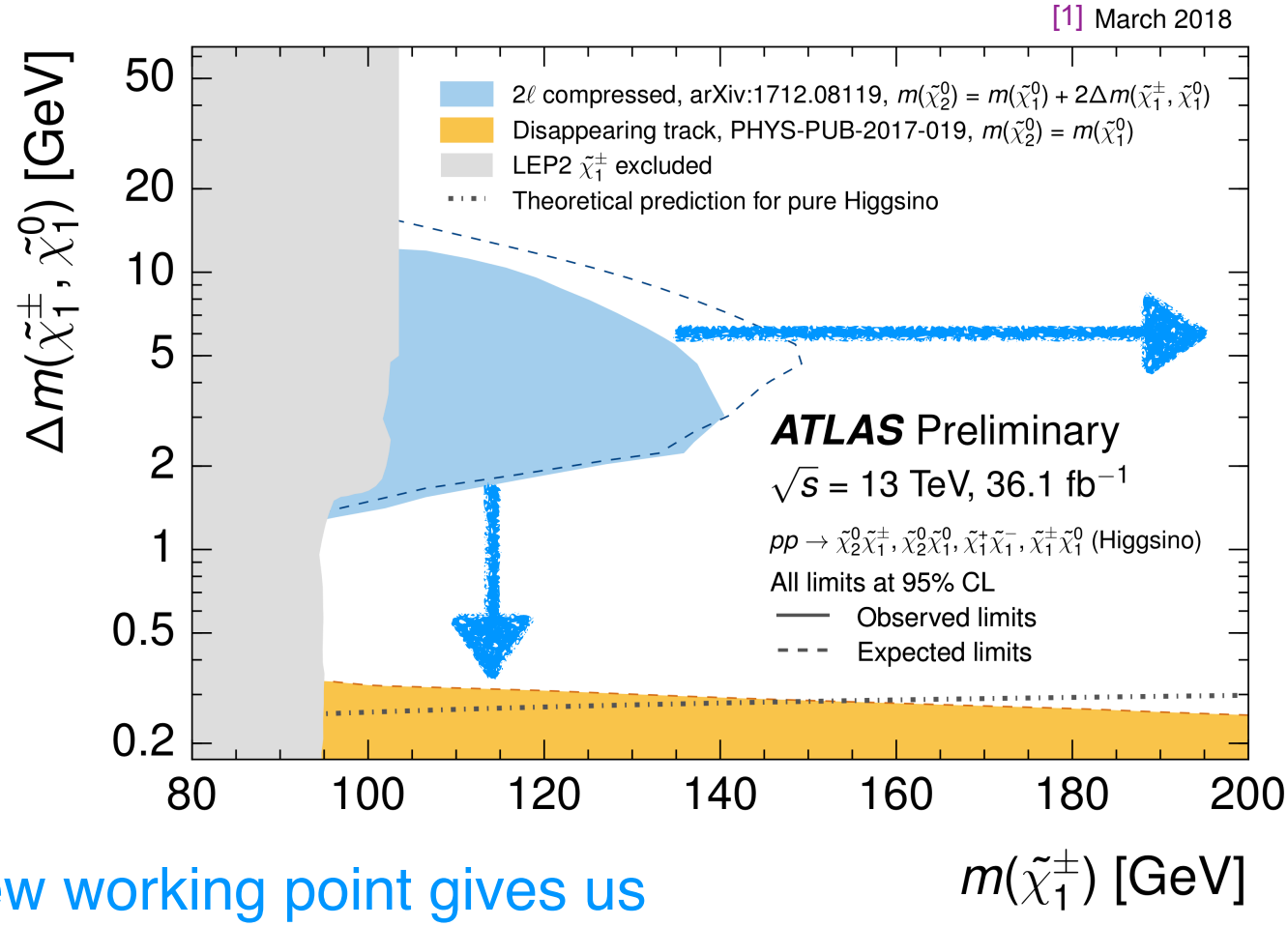

More luminosity

New working point gives us muons down to 3 GeV (2019)

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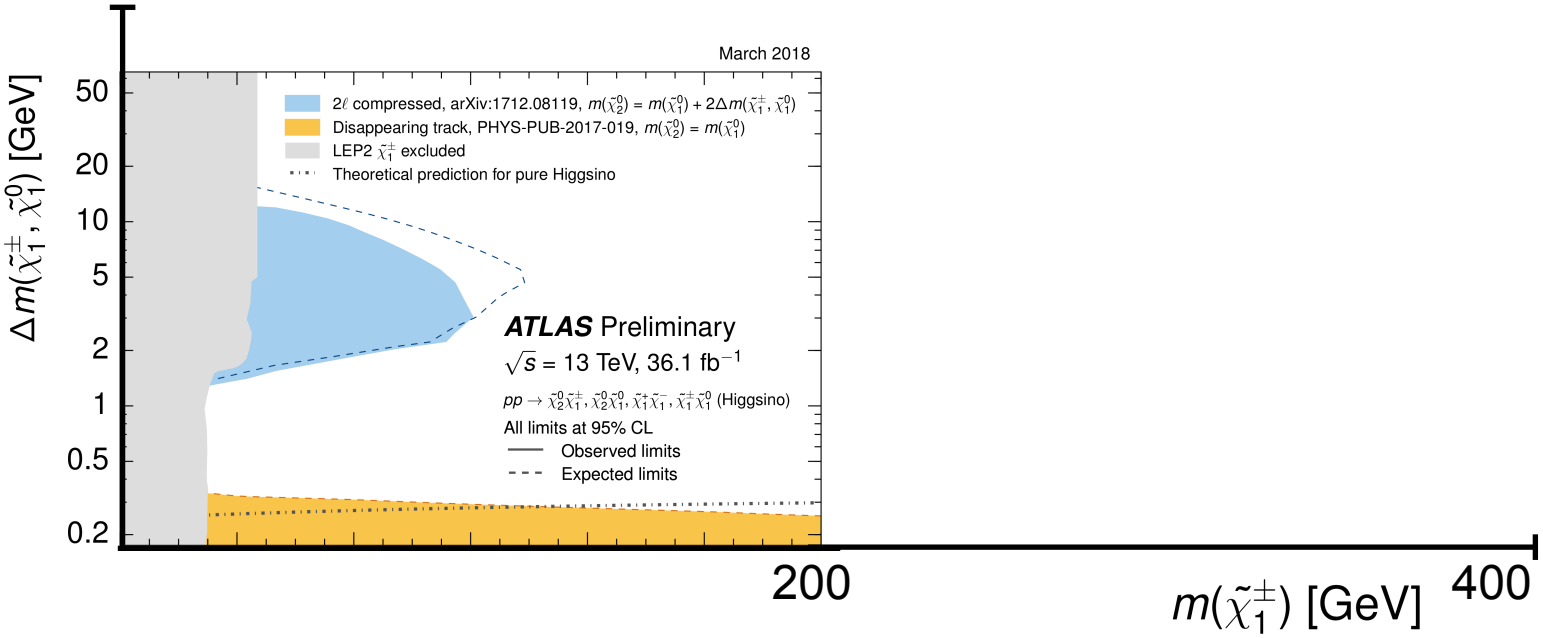
What's Next?

- **Natural SUSY is still well-motivated!** (& experimental constraints are weakest in the electroweak sector)



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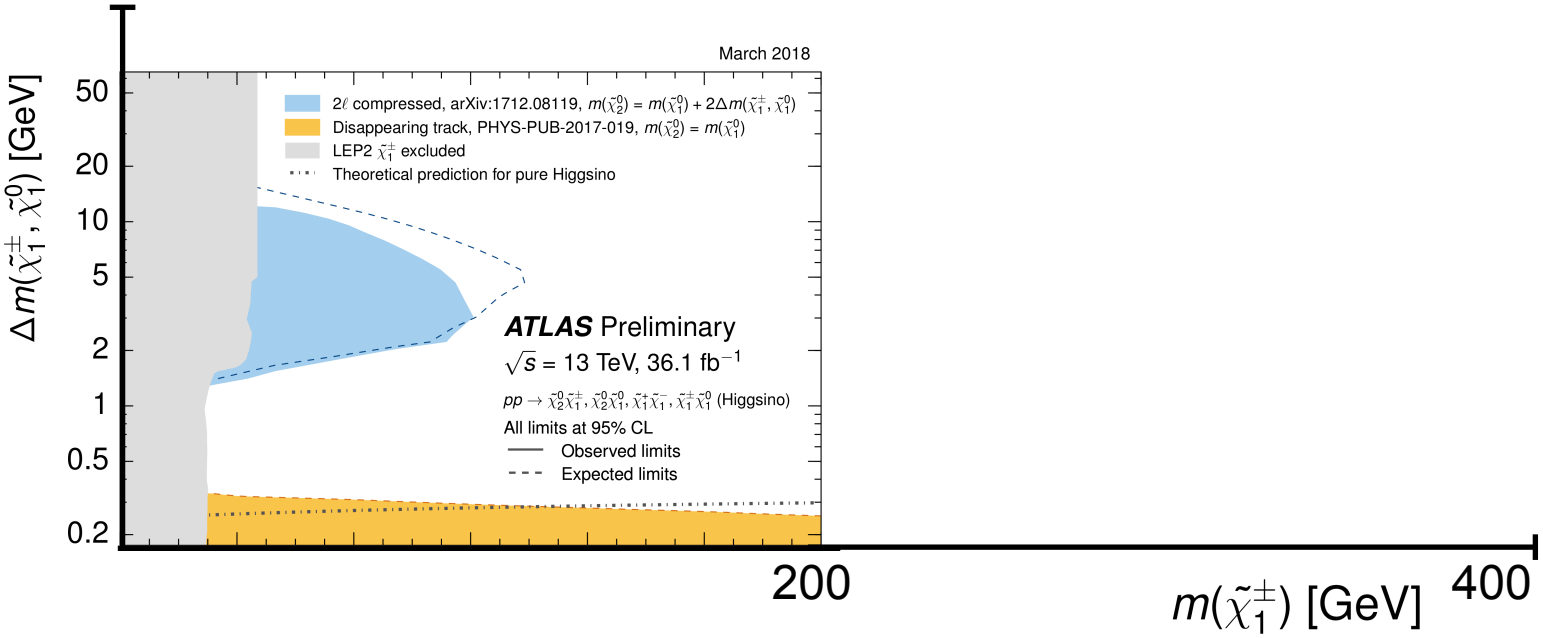
  - Fine tuning < 10% possible for m($\tilde{g}$) < 2.5 TeV and m($\tilde{t}$) < 1.5 TeV [4]



[4] arXiv:1611.05873

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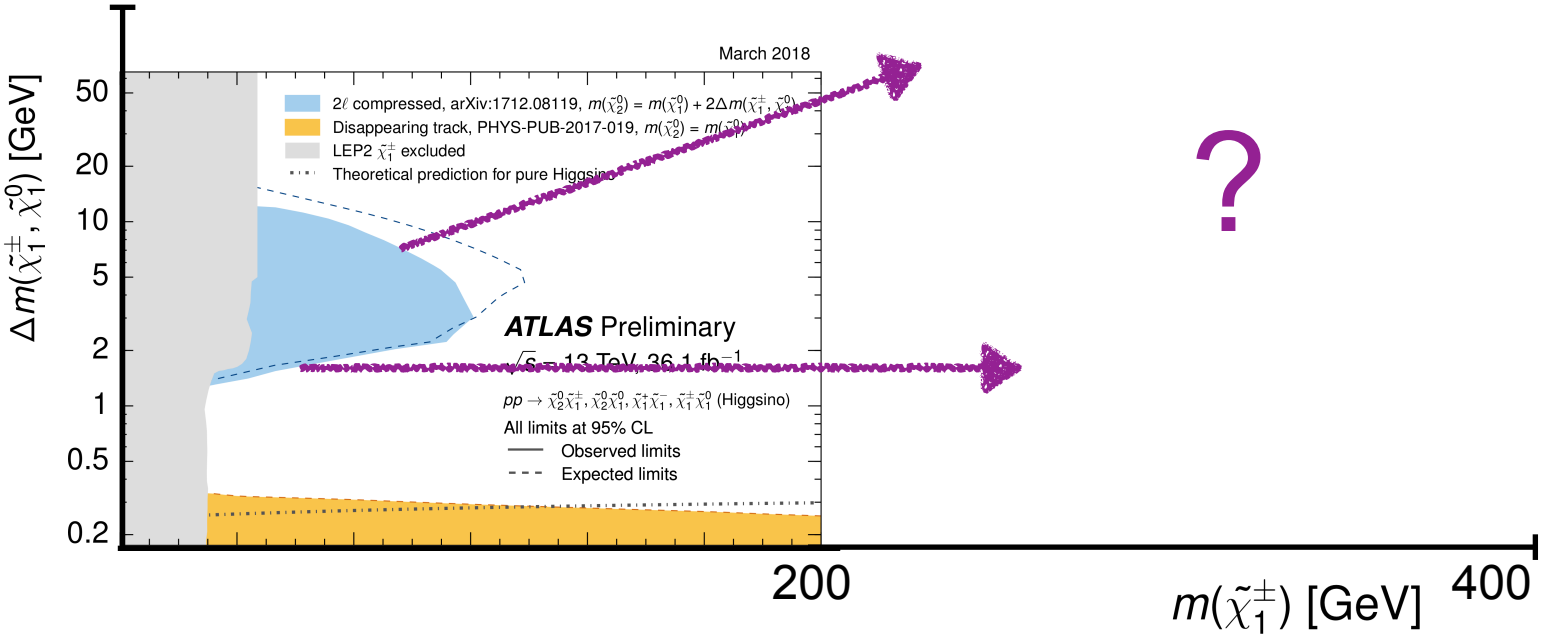
- Up next: softer leptons, 1L + track, **HL-LHC! (2026+)**



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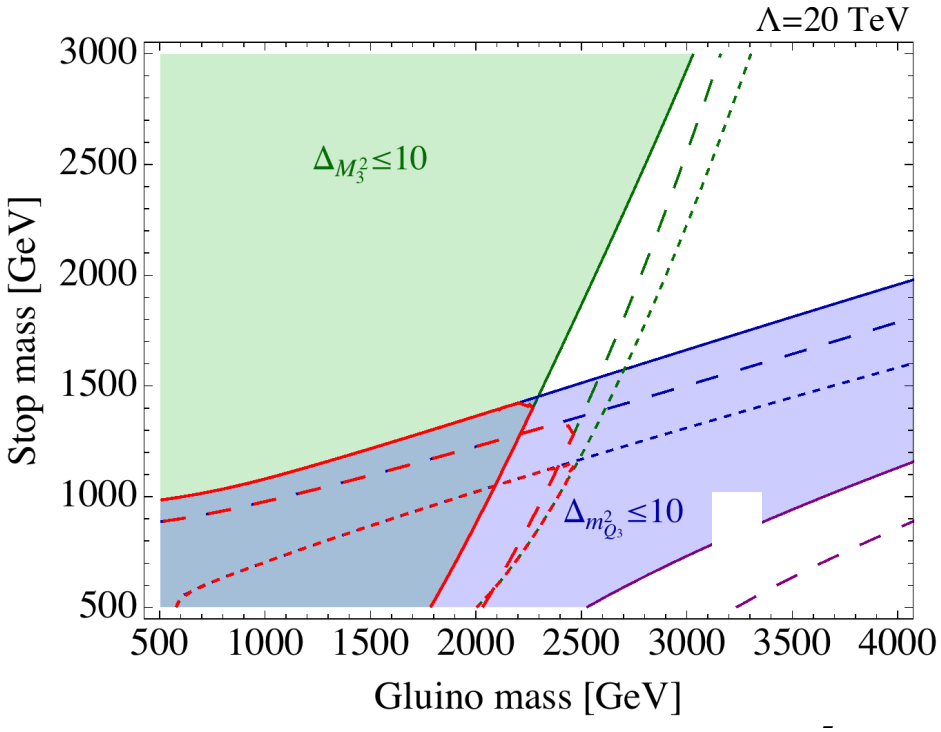
Backup

Precision Corrections to Fine Tuning

Buckley, Monteux, Shih arXiv:1611.05873



$$m_H^2 = m_{H,bare}^2 + \Delta m^2 - \Delta m^2$$

$$\Delta m^2 = |\mu|^2 \quad \text{(at tree level)}$$

$$\Delta \equiv \frac{2\delta m_H^2}{m_h^2} \leq 10$$

$$\mu \leq 400 GeV$$

Why Quasi-Degenerate?

Depends on neutrino mass matrix in MSSM! Using $(\widetilde{B}^0, \widetilde{W}^0, \psi_d^0, \psi_u^0)$ basis

$$M_{\tilde{N}^0} = \begin{pmatrix} M_1 & 0 & -m_W t_{\theta_W} c_\beta & m_W t_{\theta_W} s_\beta \\ 0 & M_2 & m_W c_\beta & -m_W s_\beta \\ -m_W t_{\theta_W} c_\beta & m_W c_\beta & 0 & -\mu \\ m_W t_{\theta_W} s_\beta & -m_W s_\beta & -\mu & 0 \end{pmatrix} \qquad M_{\tilde{C}} = \begin{pmatrix} M_2 & \sqrt{2} s_\beta m_W \\ \sqrt{2} c_\beta m_W & \mu \end{pmatrix}$$

$$\left| m_{\chi_1^\pm} \right| - \left| m_{\chi_1^0} \right| \approx \frac{m_W^2 (1 \mp s_{2\beta})}{2(M_2 + |\mu|)}$$

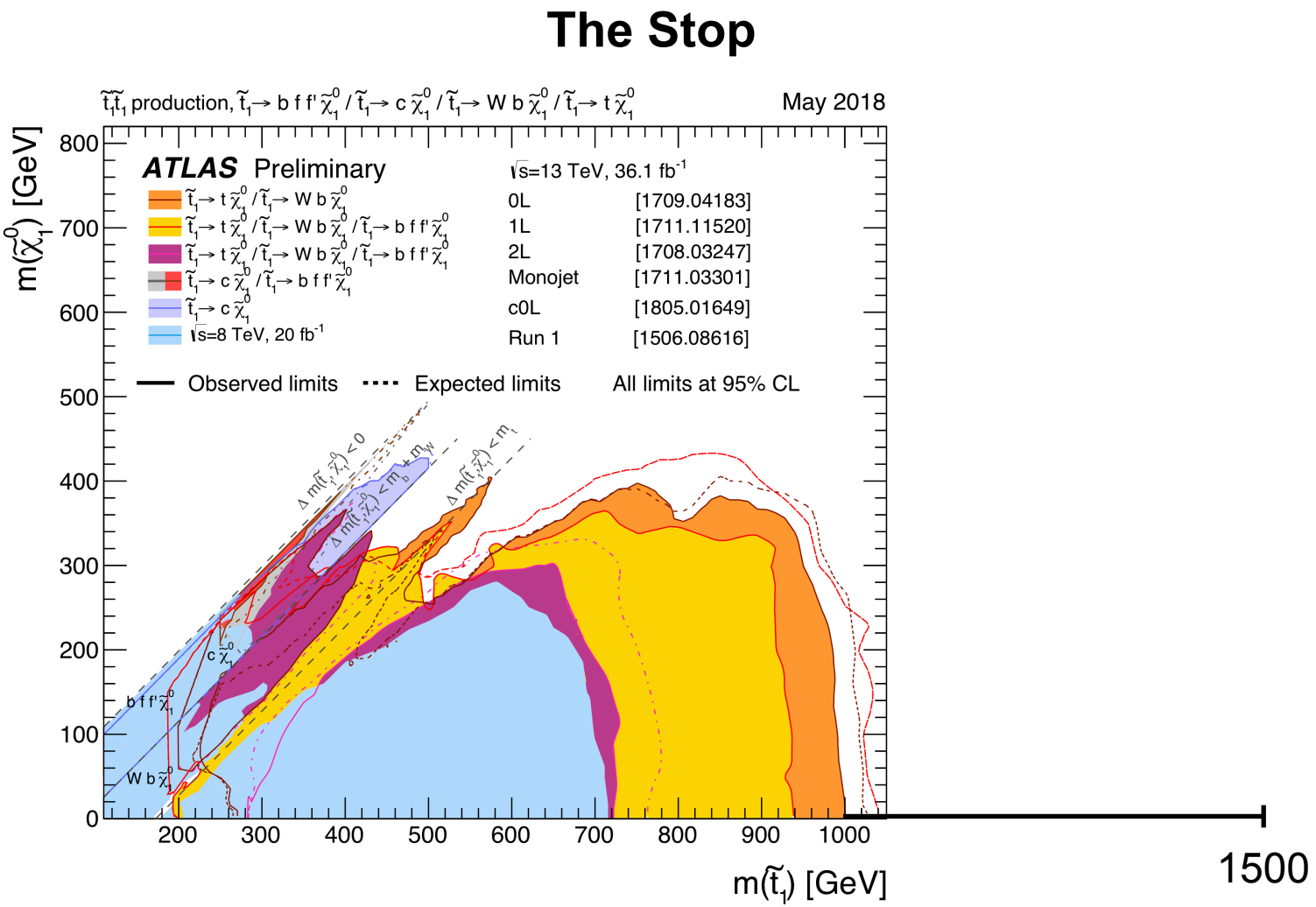
$$\left| m_{\chi_2^0} \right| - \left| m_{\chi_1^\pm} \right| \approx \frac{m_W^2 (1 \pm s_{2\beta})}{2(M_2 - |\mu|)}, \qquad \left| m_{\chi_2^0} \right| - \left| m_{\chi_1^0} \right| \approx \frac{m_W^2 \left(\pm |\mu| \, s_{2\beta} + M_2 \right)}{(M_2^2 - |\mu|^2)}$$

Wino/bino as lightest electroweakino, # light states is different!

- one neutral state for a light bino;
- one neutral and one charged state for a light wino.

arXiv:1401.1235

But we haven't found anything yet!



Limits up-to ~1 TeV in stop mass … but no limits if m(LSP) ≳ 400 GeV

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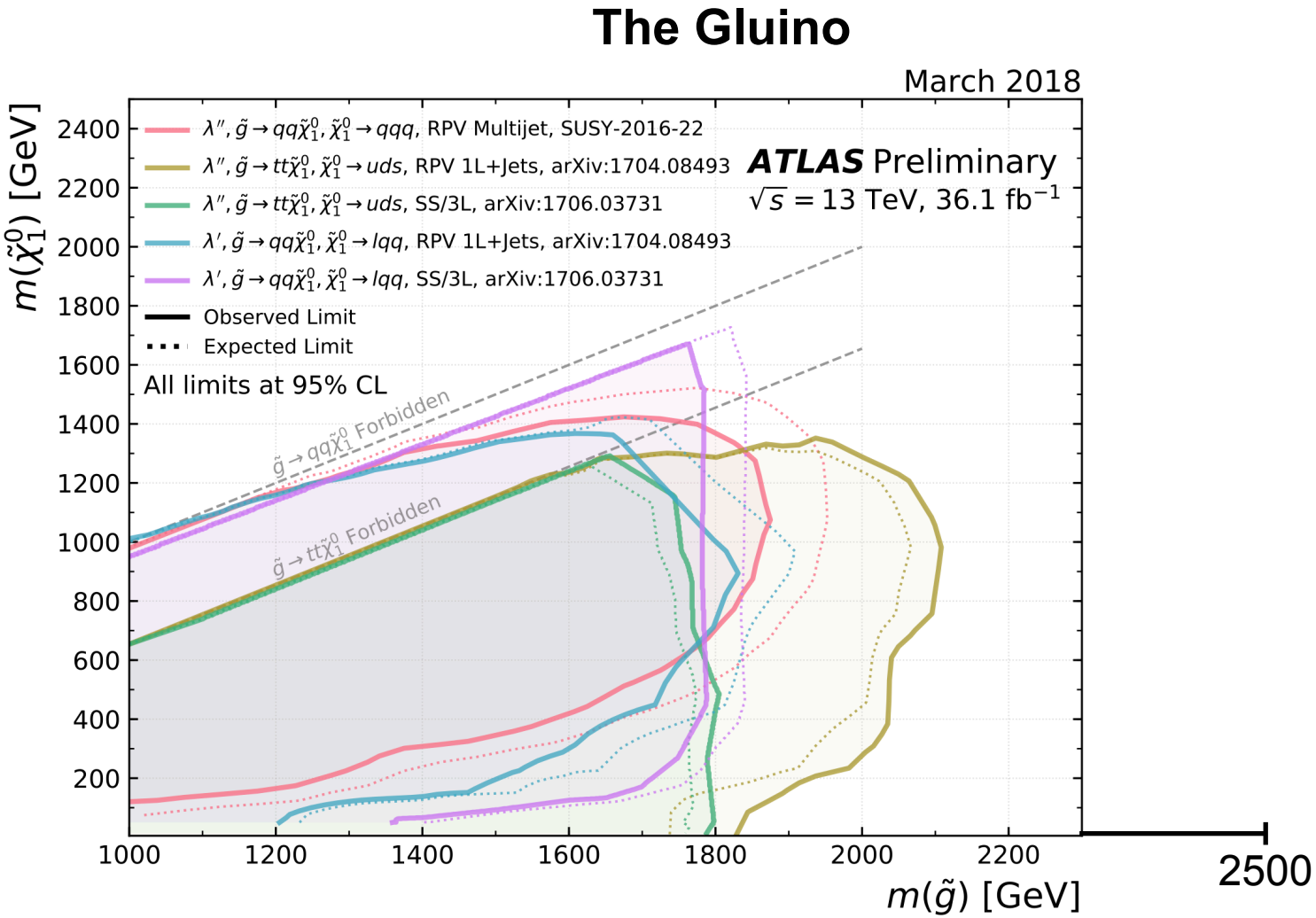
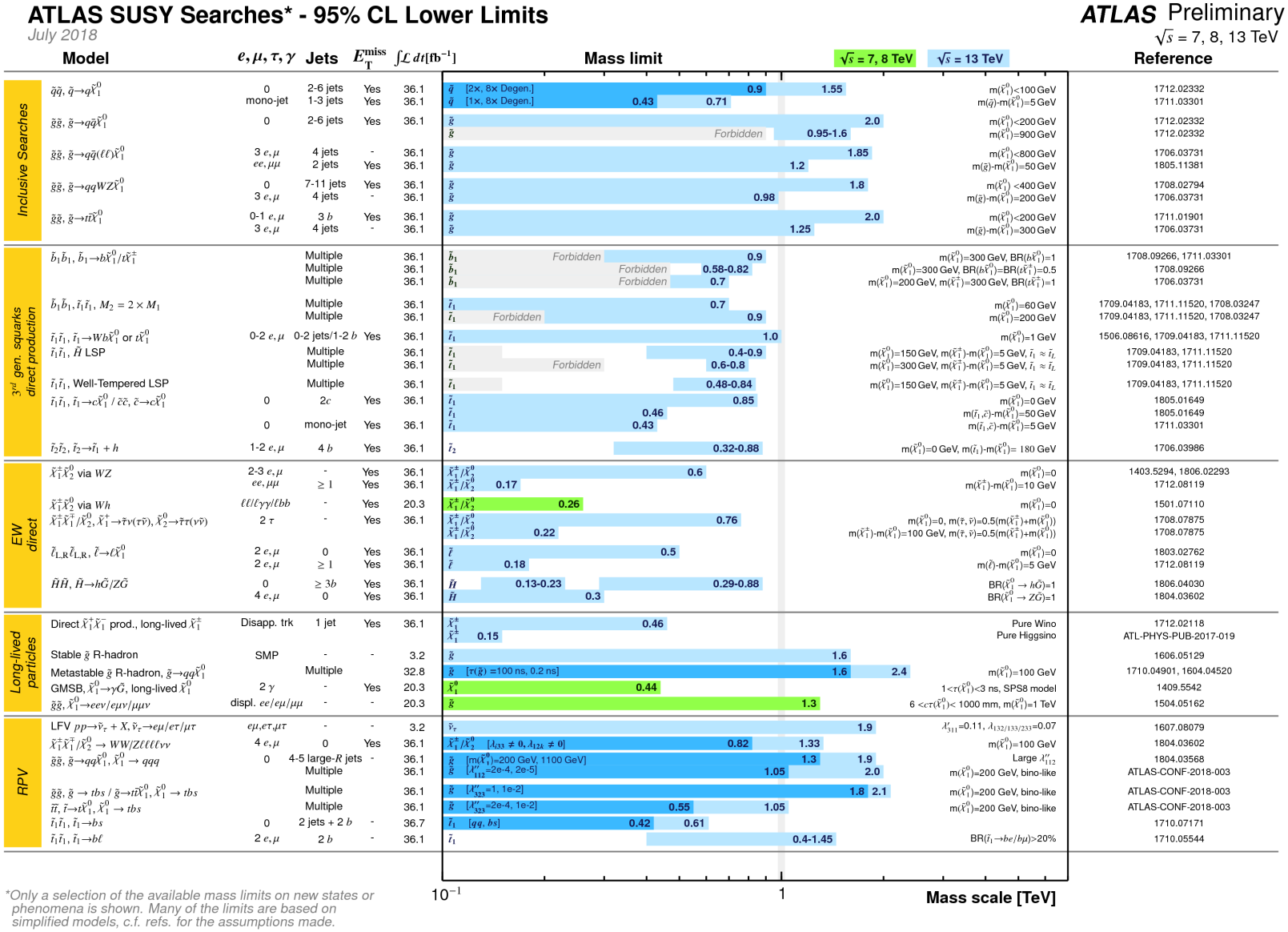


ATLAS SUSY Summary

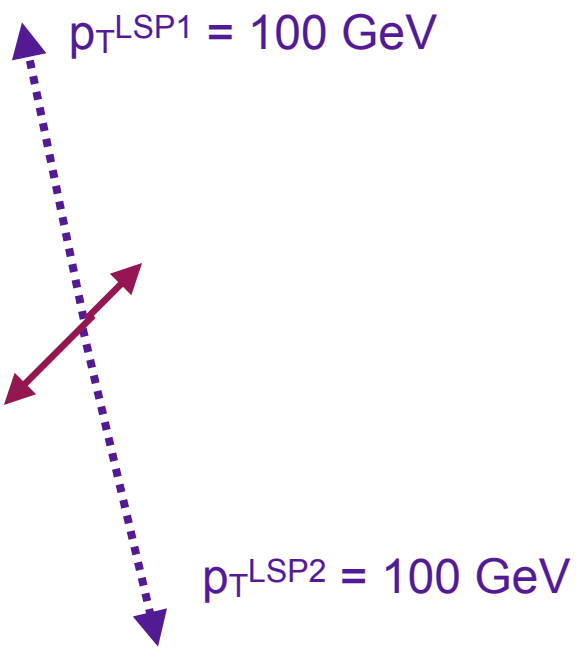


2L Higgsino Search

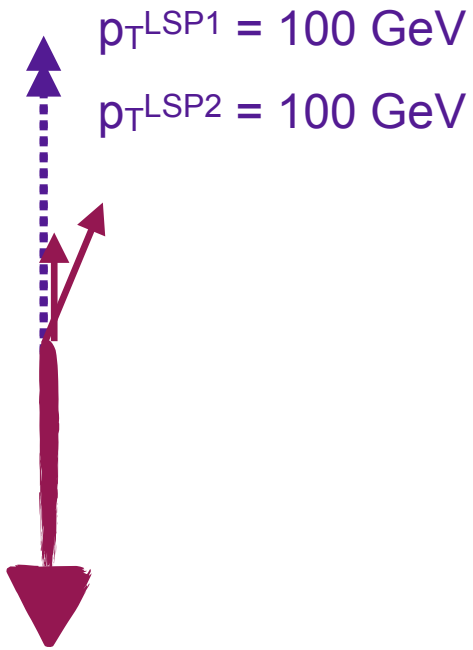
- **Met** > 200 GeV → trigger
- $\mathbf{p_T(jet1)}$>200 GeV → ISR
- $|\boldsymbol{\Delta\phi}\mathbf{(jet,Met)}|$ > 1.0 → mis-measured Met
- **nJet(50 GeV)**=1,2 → no jets expected from the signal
- **bJet veto** → ttbar background
- **upper cut on lepton $\mathbf{p_T}$** → soft leptons in the final state;
- **upper cut on $\mathbf{m_{ll}}$** → small invariant masses expected;
- **Met/Ht** → good discrimination as seen in the Run-2 analysis;
- $\mathbf{m}\tau\tau$ → $Z\tau\tau$ background;

Making E_T^{miss} with ISR

- With no other final state objects, LSPs are back to back, no E_T^{miss} in event
- Require ISR jet: collimate LSPs, generate measurable E_T^{miss} for trigger



Total E_T^{miss} = 0 GeV



Total E_T^{miss} = 200 GeV